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PTO/SB/21 (09-04) (AW 10/2004)

JRW

TRANSMITTAL FORM

(to be used for all correspondence after initial filing)

Total Number of Pages in This Submission 5

Application Number	10/676,654
Filing Date	October 1, 2003
First Named Inventor	Koji Takinami et al.
Art Unit	2817
Examiner Name	Joseph Chang
Attorney Docket No.	MTS-3475US

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Remarks:

SIGNATURE OF APPLICANT, ATTORNEY OR AGENT

Firm Name	RatnerPrestia		
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Printed Name	Daniel N. Calder		
Date	September 9, 2005	Registration No.	27,424

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of 1-chome, okutenjin-cho, Takatsuki-shi, Osaka, 569-1118 JAPAN
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This is to certify that the annexed is
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Date of Application : October 3, 2002
Application Number : JP2002-291632
Applicant(s) : MATSUSHITA ELECTRIC
INDUSTRIAL CO., LTD

wafer
of the
Patent
Office

June 12, 2003

Commissioner,
Patent Office

Shinichiro Ota
Appln. Cert. 2003-3045993

(TRANSLATION)

[Document] Application for Patent

[Reference Number] 2022040178

[Filing Date] October 3, 2002

[Direction] Director-General of the Patent Office

[I. P. C.] H03B 5/08

 H03B 7/06

 H03C 3/22

[Inventor]

[Address] 1006, Oaza Kadoma, Kadoma-shi, Osaka
 c/o Matsushita Electric Industrial Co., Ltd.

[Name] Koji TAKINAMI

[Inventor]

[Address] 1006, Oaza Kadoma, Kadoma-shi, Osaka
 c/o Matsushita Electric Industrial Co., Ltd.

[Name] Hisashi ADACHI

[Inventor]

[Address] 1006, Oaza Kadoma, Kadoma-shi, Osaka
 c/o Matsushita Electric Industrial Co., Ltd.

[Name] Tokio ENDOH

[Patent Applicant]

[Identification Number] 000005821

[Name] Matsushita Electric Industrial Co., Ltd.

[Attorney]

[Identification Number] 100092794

[Patent attorney]

[Name] Masamichi MATSUDA

[Phone] 06-6397-2840

[Official Fee]

[Ledger Number] 009896

[Amount] 21000

[List of Attached Documents]

[Document] Specification 1 copy

[Document] Drawing 1 copy

[Document] Abstract 1 copy

[General Authorization Number] 9006027

[Proof] Yes

[Document Name] SPECIFICATION

[TITLE OF THE INVENTION]

VOLTAGE-CONTROLLED OSCILLATOR, RADIO COMMUNICATION

APPARATUS AND VOLTAGE-CONTROLLED OSCILLATION METHOD

[Scope of Claims]

[Claim 1] A voltage-controlled oscillator having:

an inductor circuit having an inductor and a power supply terminal;

n pieces (n is two or more) of variable capacitance circuit having a variable capacitance element and having blocking capacitors of interrupting a direct current at both ends thereof, a negative resistance circuit, and reference voltage generation means of generating a reference voltage from a power supply voltage, and wherein:

said inductor circuit, said n pieces of variable capacitance circuit and said negative resistance circuit are connected in parallel;

a predetermined reference voltage is inputted to some terminals of the variable capacitance elements of said n pieces of variable capacitance circuit;

a control voltage of feedback-controlling an oscillation frequency is inputted to the other terminals of the variable capacitance elements of said n pieces of variable capacitance circuits;

of said n pieces of variable capacitance circuits, the predetermined reference voltage inputted to one of the terminals of the variable capacitance elements of at least two of said n pieces of variable capacitance circuit is different; and

output sides of outputting said reference voltages of said reference voltage generation means are grounded via capacitors respectively.

[Claim 2] The voltage-controlled oscillator according to Claim 1, wherein, when said n pieces of variable capacitance circuits are arranged in decreasing order of reference voltages inputted to said n pieces of variable capacitance circuits, a difference between the voltage inputted to one terminal of the variable capacitance element of an m-th (m is between 2 and n) variable capacitance circuit and the voltage inputted to one terminal of the variable capacitance element of an m-1-th variable capacitance circuit is V_d .

[Claim 3] The voltage-controlled oscillator according to Claim 1 or 2, wherein said reference voltage generation means has series-connected $n+1$ pieces of resistor, and said n pieces of reference voltage are

generated by having said power supply voltage divided by said series-connected n+1 pieces of resistor.

[Claim 4] The voltage-controlled oscillator according to Claim 1 or 2, wherein said reference voltage generation means has series-connected one resistor and n pieces of diode, and said n pieces of reference voltage are generated by having said power supply voltage divided by said series-connected one resistance and n pieces of diode.

[Claim 5] The voltage-controlled oscillator according to Claim 4, wherein said diodes are formed by transistors having bases and collectors thereof shorted.

[Claim 6] The voltage-controlled oscillator according to any of Claims 3 to 5, wherein said reference voltage generation means further has an active filter.

[Claim 7] The voltage-controlled oscillator according to Claim 1 or 2, wherein said reference voltage generation means has series-connected one active filter and n pieces of resistors, and said n pieces of reference voltage are generated by having said power supply voltage

divided by said series-connected one active filter and n pieces of resistors.

[Claim 8] A voltage-controlled oscillator having:

an inductor circuit having an inductor and a power supply terminal;

a first variable capacitance circuit having a variable capacitance element, having a power supply voltage inputted to one terminal of said variable capacitance element and having a voltage according to a frequency band to be used of a plurality of voltages inputted to the other terminal of said variable capacitance element so as to change a capacitance of said variable capacitance element;

n pieces of variable capacitance circuit having a variable capacitance element and having blocking capacitors of interrupting a direct current at both ends thereof; and

a negative resistance circuit, and wherein:

said first variable capacitance circuit, said n pieces of variable capacitance circuit and said negative resistance circuit are connected in parallel;

a power supply voltage or a predetermined reference voltage is inputted to some terminals of the variable

capacitance elements of said n pieces of variable capacitance circuit; and

when the capacitance of the variable capacitance element of said first variable capacitance circuit becomes less than a predetermined value, a variable range is reduced as to the capacitance of at least one variable capacitance circuit of said n pieces of variable capacitance circuit.

[Claim 9] The voltage-controlled oscillator according to Claim 8, wherein at least one variable capacitance circuit of said n pieces of variable capacitance circuit has at least one variable capacitance element, and the voltage according to a frequency to be used of said plurality of voltages is inputted to the other terminal of at least one of said variable capacitance elements instead of said control voltage so that the variable range is reduced as to the capacitance of at least one variable capacitance circuit of said n pieces of variable capacitance circuit according to the reduction in the capacitance of the variable capacitance element of said first variable capacitance circuit.

[Claim 10] The voltage-controlled oscillator according to Claim 8, wherein said blocking capacitor

is comprised of two or more capacitors connected via a switch, and said switch is off or on according to the frequency to be used so that the capacitance of said blocking capacitors is reduced and a variable range of the capacitance of at least one of said n pieces of variable capacitance circuit is reduced.

[Claim 11] The voltage-controlled oscillator according to any of Claims 1 to 10, wherein said variable capacitance element operates by utilizing a gate capacitance of an MOS transistor.

[Claim 12] A radio communication apparatus having a radio communication apparatus having a PLL circuit of outputting a signal of a target frequency having the voltage-controlled oscillator according to any of Claims 1 to 11.

[Claim 13] A voltage-controlled oscillation method of a voltage-controlled oscillator having:

an inductor circuit having an inductor and a power supply terminal;

n pieces (n is two or more) of variable capacitance circuit having a variable capacitance element and having blocking capacitors of interrupting a direct current at

both ends thereof, a negative resistance circuit, and reference voltage generation means of generating a reference voltage from a power supply voltage, with said inductor circuit, said n pieces of variable capacitance circuit and said negative resistance circuit connected in parallel, and wherein there are:

a step of inputting a predetermined reference voltage to some terminals of the variable capacitance elements of said n pieces of variable capacitance circuit; and

a step of inputting a control voltage of feedback-controlling an oscillation frequency to the other terminals of the variable capacitance elements of said n pieces of variable capacitance circuits, and

the predetermined reference voltage inputted to one of the terminals of the variable capacitance elements of at least two of said n pieces of variable capacitance circuit is different, and

output sides of outputting said reference voltages of said reference voltage generation means are grounded via capacitors respectively.

[Detailed Description of the Invention]

[0001]

[Field of the Invention]

The present invention relates to a voltage-controlled oscillator used for a radio communication device, a radio communication apparatus using the voltage-controlled oscillator and a voltage-controlled oscillation method.

[0002]

[Prior Art]

A voltage-controlled oscillator is widely used as a means of generating a local oscillation signal of a radio communication device.

[0003]

Fig. 12 shows a configuration example of such a voltage-controlled oscillator in the past.

[0004]

In Fig. 12, reference numerals 1a and 1b denote oscillation transistors, 2a and 2b denote inductors, and 3a and 3b denote variable capacitance elements. Reference numeral 4 denotes a power supply terminal, 5 denotes a frequency control terminal, and 6 denotes a current source. A bias circuit and so on are omitted in Fig. 12.

[0005]

Hereafter, operation of the voltage-controlled oscillator in the past will be described by referring to Fig. 12.

[0006]

In Fig. 12, the inductors 2a and 2b and variable capacitance elements 3a and 3b constitute a parallel resonant circuit. As a capacitance value of the variable capacitance element changes due to a difference in voltages at both ends thereof, the capacitance values of the variable capacitance elements 3a and 3b change due to a control voltage applied to the frequency control terminal 5, and consequently a resonance frequency of the parallel resonant circuit changes.

[0007]

As an oscillation frequency of the voltage-controlled oscillator oscillates in the neighborhood of the resonance frequency of the resonant circuit, it is possible, by adjusting control voltage, to control the oscillation frequency of the voltage-controlled oscillator to be a desired frequency. The oscillation transistors 1a and 1b are intended to generate negative resistance and cancel losses due to a parasitic resistance component of the resonant circuit so as to satisfy an oscillation requirement.

[0008]

Here, a relationship between the control voltage and the oscillation frequency of the voltage-controlled oscillator is virtually determined by a characteristic of the variable capacitance element, and so the variable capacitance element to be used is desired to change the capacitance slowly in a wide range of the control voltage. It is because, in the case of constituting a PLL (phase lock loop) by using the voltage-controlled oscillator, a transient response characteristic and a noise band characteristic of a PLL circuit depend on frequency sensitivity against the control voltage. Therefore, if the frequency sensitivity is different according to the frequency, the characteristic of the PLL circuit itself changes according to the frequency. In an area where the frequency sensitivity against the control voltage is high, there is a problem that a phase noise characteristic is degraded because the frequency changes due to slight noise caused on a frequency control terminal.

[0009]

In reality, however, it is difficult to utilize the variable capacitance element of high linearity because, when implementing the voltage-controlled oscillator on a semiconductor substrate, the costs are increased by introducing a special process for the sake of forming

the variable capacitance element. Fig. 13 (a) shows the variable capacitance element utilizing a gate capacitance widely used in a CMOS process, and Fig. 13 (b) shows the variation of the gate capacitance in the case of applying the reference voltage to the gate of a MOS transistor and applying the control voltage to a drain-source side. Thus, in the case of the variable capacitance element utilizing the gate capacitance of the MOS transistor generally used, the capacitance value abruptly changes in the neighborhood of a threshold voltage (V_{th} in the drawing) so that the oscillation frequency also abruptly changes in an area in the neighborhood of a threshold. Consequently, there arises a problem that the transient response characteristic and noise band characteristic of the PLL circuit using this VCO significantly change depending on the frequency.

[0010]

The circuit described below has already been proposed in order to solve such problems.

[0011]

Fig. 14 is the circuit showing a technique of improving the linearity of the variable capacitance element in the past (refer to Patent Document 1 for instance). In Fig. 14, the same portions as those previously described are

given the same symbols and a description thereof will be omitted.

[0012]

Reference numerals 10a, 10b, 11a, 11b, 12a and 12b denote the variable capacitance elements, and 13 denotes a level shift circuit. A control signal inputted from the frequency control terminal 5 is inputted to the level shift circuit 13, and voltages having shifted by V_d such as V_t , $V_t - V_d$ and $V_t - 2V_d$ are outputted from three output terminals outputted from the above described level shift circuit. In this case, the characteristics of the variable capacitance elements (10a to 12b) against the control voltage V_t are the characteristics shifted by V_d as shown in Fig. 15. As the capacitance of the resonant circuit is a total of these six capacitances, a total capacitance thereof is the characteristic indicated by a dashed line in Fig. 15 (A in Fig. 15) so that the change in the capacitance against the control voltage can be moderate.

[0013]

[Patent Document 1]

Japanese Patent Laid-open No. 2001-352218

[0014]

[Problems to be Solved by the Invention]

However, the conventional improving method as described above has a problem in that the phase noise characteristic of the voltage-controlled oscillator is degraded since the control voltage is inputted to the level shift circuit to generate offset output signals. It is because the oscillation frequency of the voltage-controlled oscillator is extremely influenced by a control voltage, and changed even due to a slight noise caused on a control voltage.

[0015]

Moreover, in the case that a grounded capacitor is inserted into an output signal line out of the level shift circuit in order to curb degrading the phase noise characteristic of the voltage-controlled oscillator, it is difficult to utilize a capacitor of a large capacitance since a transient response characteristic and a noise band characteristic of the voltage-controlled oscillator is influenced by the grounded capacitor. In other words, when the grounded capacitor of the large capacitance is inserted into the output signal line out of the level shift circuit in order to improve the phase noise characteristic, the compliance is reduced in the case that a control voltage inputted from the frequency control terminal 5 changes. Accordingly, to keep the compliance of the control voltage unreduced, there still is a problem

in that the capacitance of the above grounded capacitor is limited, and it is impossible to obtain a sufficient effect on curbing noise with such a grounded capacitor of the limited capacitance.

[0016]

In consideration of the above problems, an object of the present invention is to provide a voltage-controlled oscillator capable of curbing degradation of a phase noise characteristic and keeping compliance of a control voltage unreduced, a radio communication apparatus using the voltage-controlled oscillator and a voltage-controlled oscillation method, or to provide the voltage-controlled oscillator, radio communication apparatus and voltage-controlled oscillation method capable of curbing degradation of the phase noise characteristic.

[0017]

[Means to Solve the Problem]

A first present invention is a voltage-controlled oscillator having:

an inductor circuit having an inductor and a power supply terminal;

n pieces (n is two or more) of variable capacitance circuit having a variable capacitance element and having blocking capacitors of interrupting a direct current at

both ends thereof, a negative resistance circuit, and reference voltage generation means of generating a reference voltage from a power supply voltage, and wherein:

 said inductor circuit, said n pieces of variable capacitance circuit and said negative resistance circuit are connected in parallel;

 a predetermined reference voltage is inputted to some terminals of the variable capacitance elements of said n pieces of variable capacitance circuit;

 a control voltage of feedback-controlling an oscillation frequency is inputted to the other terminals of the variable capacitance elements of said n pieces of variable capacitance circuits;

 of said n pieces of variable capacitance circuits, the predetermined reference voltage inputted to one of the terminals of the variable capacitance elements of at least two of said n pieces of variable capacitance circuit is different; and

 output sides of outputting said reference voltages of said reference voltage generation means are grounded via capacitors respectively.

[0018]

 A second present invention is the voltage-controlled oscillator according to the first present invention,

wherein, when said n pieces of variable capacitance circuits are arranged in decreasing order of reference voltages inputted to said n pieces of variable capacitance circuits, a difference between the voltage inputted to one terminal of the variable capacitance element of an m-th (m is between 2 and n) variable capacitance circuit and the voltage inputted to one terminal of the variable capacitance element of an m-1-th variable capacitance circuit is Vd.

[0019]

A third present invention is the voltage-controlled oscillator according to the first or the second present invention, wherein said reference voltage generation means has series-connected n+1 pieces of resistor, and said n pieces of reference voltage are generated by having said power supply voltage divided by said series-connected n+1 pieces of resistor.

[0020]

A fourth present invention is the voltage-controlled oscillator according to the first or the second present invention, wherein said reference voltage generation means has series-connected one resistor and n pieces of diode, and said n pieces of reference voltage are generated by having said power supply voltage divided by said series-connected one resistance and n pieces of diode.

[0021]

A fifth present invention is the voltage-controlled oscillator according to the fourth present invention, wherein said diodes are formed by transistors having bases and collectors thereof shorted.

[0022]

A sixth present invention is the voltage-controlled oscillator according to any of the third to the fifth present inventions, wherein said reference voltage generation means further has an active filter.

[0023]

A seventh present invention is the voltage-controlled oscillator according to the first or the second present invention, wherein said reference voltage generation means has series-connected one active filter and n pieces of resistors, and said n pieces of reference voltage are generated by having said power supply voltage divided by said series-connected one active filter and n pieces of resistors.

[0024]

An eighth present invention is a voltage-controlled oscillator having:

an inductor circuit having an inductor and a power supply terminal;

a first variable capacitance circuit having a variable capacitance element, having a power supply voltage inputted to one terminal of said variable capacitance element and having a voltage according to a frequency band to be used of a plurality of voltages inputted to the other terminal of said variable capacitance element so as to change a capacitance of said variable capacitance element;

n pieces of variable capacitance circuit having a variable capacitance element and having blocking capacitors of interrupting a direct current at both ends thereof; and

a negative resistance circuit, and wherein: said first variable capacitance circuit, said n pieces of variable capacitance circuit and said negative resistance circuit are connected in parallel;

a power supply voltage or a predetermined reference voltage is inputted to some terminals of the variable capacitance elements of said n pieces of variable capacitance circuit; and

when the capacitance of the variable capacitance element of said first variable capacitance circuit becomes less than a predetermined value, a variable range is reduced as to the capacitance of at least one variable

capacitance circuit of said n pieces of variable capacitance circuit.

[0025]

A ninth present invention is the voltage-controlled oscillator according to the eighth present invention, wherein at least one variable capacitance circuit of said n pieces of variable capacitance circuit has at least one variable capacitance element, and the voltage according to a frequency to be used of said plurality of voltages is inputted to the other terminal of at least one of said variable capacitance elements instead of said control voltage so that the variable range is reduced as to the capacitance of at least one variable capacitance circuit of said n pieces of variable capacitance circuit according to the reduction in the capacitance of the variable capacitance element of said first variable capacitance circuit.

[0026]

A tenth present invention is the voltage-controlled oscillator according to the eighth present invention, wherein said blocking capacitor is comprised of two or more capacitors connected via a switch, and said switch is off or on according to the frequency to be used so that the capacitance of said blocking capacitors is reduced and a variable range of the capacitance of at

least one of said n pieces of variable capacitance circuit is reduced.

[0027]

An eleventh present invention is the voltage-controlled oscillator according to any of the first to the tenth present inventions, wherein said variable capacitance element operates by utilizing a gate capacitance of an MOS transistor.

[0028]

A twelfth present invention is a radio communication apparatus having a radio communication apparatus having a PLL circuit of outputting a signal of a target frequency having the voltage-controlled oscillator according to any of the first to the eleventh inventions.

[0029]

A thirteenth present invention is a voltage-controlled oscillation method of a voltage-controlled oscillator having:

an inductor circuit having an inductor and a power supply terminal;

n pieces (n is two or more) of variable capacitance circuit having a variable capacitance element and having blocking capacitors of interrupting a direct current at both ends thereof, a negative resistance circuit, and reference voltage generation means of generating a

reference voltage from a power supply voltage, with said inductor circuit, said n pieces of variable capacitance circuit and said negative resistance circuit connected in parallel, and wherein there are:

a step of inputting a predetermined reference voltage to some terminals of the variable capacitance elements of said n pieces of variable capacitance circuit; and

a step of inputting a control voltage of feedback-controlling an oscillation frequency to the other terminals of the variable capacitance elements of said n pieces of variable capacitance circuits, and

the predetermined reference voltage inputted to one of the terminals of the variable capacitance elements of at least two of said n pieces of variable capacitance circuit is different, and

output sides of outputting said reference voltages of said reference voltage generation means are grounded via capacitors respectively.

[0030]

[Embodiments of the Invention]

Hereafter, embodiments of the present invention will be described by referring to the drawings.

[0031]

(First Embodiment)

Fig. 1 shows a configuration of a voltage-controlled oscillator according to a first embodiment of the present invention, in which a bias circuit and so on is omitted.
[0032]

In Fig. 1, reference numeral 100 denotes a power source terminal as an example of a power supply terminal of the present invention, 101 denotes a current source, and 102 denotes a frequency control terminal. Reference numerals 103a and 103b denote oscillation transistors, 104a and 104b denote inductors, 105a, 105b, 106a, 106b, 107a and 107b denote variable capacitance elements utilizing a gate capacitance used in a CMOS process, and 108a, 108b, 109a, 109b, 110a and 110b denote DC-cut capacitors as an example of a blocking capacitor of the present invention. Reference numerals 111a, 111b, 112a, 112b, 113a and 113b denote high-frequency blocking resistances, and 114 denotes reference voltage generation means.

[0033]

The inductors 104a and 104b are series-connected, where the power source terminal 100 is connected to a connection point thereof so as to form an inductor circuit of the present invention. The variable capacitance elements 105a and 105b are connected on a drain side and a source side, and the DC-cut capacitors 108a and 108b

of interrupting direct currents are series-connected to both sides of a series circuit of the variable capacitance elements 105a and 105b. The series circuit (hereafter, referred to as a variable capacitance circuit A) of the variable capacitance elements 105a and 105b and the DC-cut capacitors 108a and 108b constitutes the variable capacitance circuit of the present invention. Likewise, the series circuit (hereafter, referred to as a variable capacitance circuit B) of the variable capacitance elements 106a and 106b and the DC-cut capacitors 109a and 109b and the series circuit (hereafter, referred to as a variable capacitance circuit C) of the variable capacitance elements 107a and 107b and the DC-cut capacitors 110a and 110b constitute the variable capacitance circuits of the present invention. The oscillation transistors 103a and 103b constitute a negative resistance circuit of the present invention. And the above inductor circuit, variable capacitance circuits A, B and C and the negative resistance circuit of the present invention are mutually connected in parallel.

[0034]

The frequency control terminal 102 is connected to the connection point of the variable capacitance elements 105a and 105b in the variable capacitance circuit A, the

connection point of the variable capacitance elements 106a and 106b in the variable capacitance circuit B, and the connection point of the variable capacitance elements 107a and 107b in the variable capacitance circuit C, that is, to the drain-source side as an example of one terminal of the variable capacitance element of the present invention.

[0035]

The gate sides of the variable capacitance elements 105a and 105b of the variable capacitance circuit A are connected to one output of the reference voltage generation means 114 via the resistors 111a and 111b respectively. The gate sides of the variable capacitance elements 112a and 112b of the variable capacitance circuit B are connected to another output of the reference voltage generation means 114 via the resistors 112a and 112b respectively. The gate sides of the variable capacitance elements 113a and 113b of the variable capacitance circuit C are connected to another output of the reference voltage generation means 114 via the resistors 112a and 112b respectively.

[0036]

Fig. 3 shows the configuration example of the reference voltage generation means 114. In Fig. 3, reference numeral 120 denotes the power source terminal,

Ra to Rd denote the resistors, and 122a to 122c denote grounded capacitors. Reference numeral 121a denotes an output terminal of outputting Vref as an example of a predetermined reference voltage of the present invention. Reference numeral 121b denotes the output terminal of outputting Vref-Vd as another example of the predetermined reference voltage of the present invention, and 121c denotes the output terminal of outputting Vref-2Vd as a further example of the predetermined reference voltage of the present invention.

[0037]

Hereafter, operation of the voltage-controlled oscillator according to the first embodiment will be described by referring to Fig. 3.

[0038]

As for the reference voltage generation means 114 in Fig. 3, it will be represented as follows if the voltage applied to the power source terminal 120 is Vcc and a voltage of signals outputted from the output terminals 121a to 121c is $R_b = R_c$.

[0039]

[Formula 1]

$$V_{ref} = V_{cc} \cdot (R_b + R_c + R_d) / (R_a + R_b + R_c + R_d)$$

$$V_{ref} - V_d = V_{cc} \cdot (R_c + R_d) / (R_a + R_b + R_c + R_d)$$

$$V_{ref} - 2V_d = V_{cc} \cdot (R_d) / (R_a + R_b + R_c + R_d)$$

It is possible, by appropriately selecting values of R_a to R_d , to generate a reference signal having an arbitrary voltage difference from the reference voltage generation means 114.

[0040]

In Fig. 1, it is assumed that an inductance of the inductors 104a and 105b is L , a capacitance value of the variable capacitance elements 105a and 105b is C_1 , the capacitance value of the variable capacitance elements 106a and 106b is C_2 , the capacitance value of the variable capacitance elements 107a and 107b is C_3 , and the capacitance value of the DC-cut capacitors 108a, 108b, 109a, 109b, 110a and 110b is C_0 . In this case, a resonance frequency f_0 of a parallel resonant circuit constituted by connecting the inductor circuit and variable capacitance circuits A, B and C in parallel is represented as follows.

[0041]

[Formula 2]

$$f_0 = 1/(2\pi(2L \cdot C'/2)^{1/2}) = 1/(2\pi(L \cdot C')^{1/2})$$

$$C' = C_1 \cdot C_0 / (C_1 + C_0) + C_2 \cdot C_0 / (C_2 + C_0) + C_3 \cdot C_0 / (C_3 + C_0)$$

[0042]

Three reference voltages different by a voltage difference V_d are outputted from the reference voltage

generation means 114 as described above. They are added to the gate side of the variable capacitance elements 105a and 105b of the variable capacitance circuit A, the gate side of the variable capacitance elements 106a and 106b of the variable capacitance circuit B, and the gate side of the variable capacitance elements 107a and 107b of the variable capacitance circuit C respectively.

[0043]

A control voltage of feedback-controlling an oscillation frequency is inputted from the frequency control terminal 102 to the drain-source side of each variable capacitance element of the variable capacitance circuits A, B and C.

[0044]

If the capacitance of each variable capacitance element changes in the neighborhood of a control voltage V_{th} when the reference voltage is V_{ref} , the capacitance values of the variable capacitance circuits A, B and C change against a frequency control voltage as in Fig. 2 (a). Therefore, a total capacitance of the variable capacitance circuits A, B and C slowly increases against the control voltage as shown in Fig. 2 (b), and as a result, change in the oscillation frequency can be rendered smooth over a wide range of the control voltage. The control

voltage in this case is the voltage difference between each reference voltage and the control voltage.

[0045]

According to the present invention, it is possible to curb degradation of a phase noise characteristic because no additional circuit such as a level shift circuit is inserted between the frequency control terminal 102 and each variable capacitance circuit. As the voltage applied to the power source terminal 100 and the reference voltage applied to the variable capacitance elements 105a, 105b, 106a, 106b, 107a and 107b are separated by the DC-cut capacitors 108a, 108b, 109a, 109b, 110a and 110b so that it also has an effect of curbing the change in the frequency due to the variation in the power supply voltage.

[0046]

The grounded capacitors 122a to 122c are bypass capacitors for the sake of suppressing noise outputted from the reference voltage generation means 114. According to the present invention, even if the capacitors are inserted in parallel into the output terminals 122a, 122b and 122c, there is no influence on a transient response characteristic and a noise band characteristic of the PLL circuit, so that the capacitors of a large capacitance value can be inserted. Furthermore, it is possible, as shown in Fig. 4, to constitute the capacitors of the large

capacitance indicated by 122d to 122f as chip components and so on on the outside of a semiconductor so as to have a further significant noise suppression effect.

[0047]

Fig. 5 is another configuration example of the reference voltage generation means 114, and the same portions as those previously described are given the same symbols. In Fig. 5, reference numerals 124a to 124c denote transistors.

[0048]

If the voltage between a base and an emitter of the transistors 124a to 124c is V_{be} , collectors and bases of the transistors 124a to 124c can be connected to operate as diodes, and so the voltage difference per stage of diodes can be approximately V_{be} .

[0049]

Therefore, it can be set up as follows.

[0050]

[Formula 3]

$$V_{ref} = 3V_{be}$$

$$V_{ref} - V_d = 2V_{be}$$

$$V_{ref} - 2V_d = V_{be}$$

As for the above circuit, even if a power supply voltage changes, the voltage difference per stage of diodes is V_{be} and it hardly changes. Therefore, it is

possible to stabilize the voltage difference of the signals outputted from the reference voltage generation means 114 so as to realize the oscillator which is hardly influenced by variation in the power supply voltage.

[0051]

Fig. 6 is another configuration example of the reference voltage generation means 114, and the same portions as those previously described are given the same symbols. In Fig. 6, reference numeral 130 denotes the transistor, 131 denotes the resistor, and 132 denotes the capacitor, and the portion surrounded by a broken line constitutes an active filter. The resistor 131 series-connected to the base of the transistor 130 and the grounded capacitor 132 constitute an LPF (low-pass filter). Here, the variable capacitance element to be used is designed to satisfy [Formula 5] in [Formula 4] in the case where a threshold voltage is V_{th} , the power supply voltage is V_{cc} , and the base-emitter voltage of the transistor is V_{be} .

[0052]

[Formula 4]

$$V_{ref} = V_{cc} - V_{be}$$

[0053]

[Formula 5]

$$V_{th} < V_{cc}$$

[0054]

According to this configuration, it is possible to eliminate the noise from a power supply with a rip filter so as to curb the variation in the reference voltage due to the noise from the power supply compared to the configuration in Fig. 5.

[0055]

As shown in Fig. 7, it is also possible, as a further configuration example of the reference voltage generation means 114, to connect the terminal 121a to the base of the transistor 130. The voltage of the terminal 121a becomes lower than the power supply voltage by V_{be} in the aforementioned configuration in Fig. 6, whereas the voltage of the terminal 121a can be set in the neighborhood of the power supply voltage in the configuration shown in Fig. 7. Therefore, it is possible to set the reference voltage in the range of 0V to the power supply voltage.

[0056]

According to this embodiment, the difference between the reference voltage outputted from the output terminal 121a of the reference voltage generation means 114 and the reference voltage outputted from the output terminal 121b and the difference between the reference voltage outputted from the output terminal 121b and the reference voltage outputted from the output terminal 121c are fixed.

However, it goes without saying that different voltage differences may be given. In that case, it should be R_b \parallel R_c as to the circuit in Fig. 3 for instance.

[0057]

The above describes the example in which there are three variable capacitance circuits connected in parallel and three reference voltages are outputted from the reference voltage generation means 114. However, it is not necessarily limited to three, but may be two in parallel or four or more in parallel in the configuration.

[0058]

In that case, there are n (n is two or more) pieces of the variable capacitance circuit as described above, and n pieces of different reference voltages are outputted from the reference voltage generation means 114 so as to be inputted to the gate side of each variable capacitance element of the n pieces of the variable capacitance circuit. And the control voltage is inputted to the drain-source side of each variable capacitance element of the n pieces of the variable capacitance circuit, so that the n pieces of output sides of the reference voltage generation means 114 should be grounded via the capacitors respectively.

[0059]

In that case, when the n pieces of variable capacitance circuits are arranged in decreasing order of reference

voltages inputted to said n pieces of variable capacitance circuits, the difference between the voltage inputted to the gate side of an m -th (m is between 2 and n) variable capacitance circuit and the voltage inputted to the gate side of an $m-1$ -th variable capacitance circuit should be V_d .

[0060]

The reference voltage generation means 114 in that case should have the configuration wherein, in the example shown in Fig. 3 for instance, $n+1$ pieces of resistors are series-connected, and the power supply voltage supplied from the power source terminal 120 is divided as n pieces of reference voltage by the $n+1$ pieces of resistor so as to be outputted.

[0061]

In the case where the reference voltage generation means is the example shown in Fig. 5 or 6, it should have the configuration wherein n pieces of diodes or transistors are series-connected, and the power supply voltage is divided as n pieces of reference voltage. In that case, the same effect as described above can be obtained.

[0062]

The above describes that the difference between the voltage inputted to the m -th variable capacitance circuit

and that inputted to the $m-1$ -th variable capacitance circuit is V_d . However, the difference between the voltages may be different values, and the same effect as described above can be obtained in that case.

[0063]

The above describes that n pieces of different reference voltages are outputted from the reference voltage generation means 114 to be inputted to the gate side of each variable capacitance element of the n pieces of the variable capacitance circuit. However, it may also be the configuration wherein n pieces of reference voltages are outputted from the reference voltage generation means 114 to be inputted to the gate side of each variable capacitance element of the n pieces of variable capacitance circuit, and at least two of the n pieces of reference voltages are different voltages. In that case, the same effect as described above can be obtained.

[0064]

(Second Embodiment)

Fig. 8 shows a configuration of the voltage-controlled oscillator according to a second embodiment of the present invention, in which the same portions as those previously described are given the same symbols and a description thereof will be omitted.

[0065]

As for the voltage-controlled oscillator according to the first embodiment, there are the cases where there is a frequency domain in which the change in the capacitance of the variable capacitance element gets saturated even if the control voltage is changed. The voltage-controlled oscillator according to this embodiment relates to the voltage-controlled oscillator capable of changing the capacitance of the variable capacitance circuit according to a frequency band.

[0066]

In Fig. 8, reference numerals 141a and 141b denote frequency band setting variable capacitance elements, 144a, 144b and 144c denote the variable capacitance circuits, and 140 denotes a terminal for frequency band setting. The variable capacitance elements 141a and 141b are mutually connected on the drain-source side to form the series circuit, constituting a first variable capacitance circuit of the present invention. The terminal for frequency band setting 140 is connected to the connection point on the drain-source side of the first variable capacitance circuit.

[0067]

Fig. 9 shows an internal configuration of the variable capacitance circuits indicated by 144a to 144c. In Fig.

9, reference numerals 200a and 200b denote connection terminals of connecting the first variable capacitance circuit and the variable capacitance circuits 144a to 144c in parallel. Here, a terminal 201 is connected to the reference voltage generation means 114 in Fig. 8, a terminal 202 is connected to the frequency control terminal 102, and a terminal 203 is connected to the frequency band setting terminal 140.

[0068]

Reference numerals 210a, 210b, 211a and 211b denote the variable capacitance elements, 212a, 212b, 213a and 213b denote the DC-cut capacitors, 214a, 214b, 215a and 215b denote high-frequency blocking resistors, and 216 denotes a switch.

[0069]

The variable capacitance elements 210a and 210b are mutually connected on the drain-source side, and the DC-cut capacitors 212a and 212b of interrupting the direct currents are series-connected to both ends of the series circuit of the variable capacitance elements 210a and 210b (hereafter, the series circuit formed by the variable capacitance elements 210a and 210b and the DC-cut capacitors 212a and 212b is referred to as a second variable capacitance circuit).

[0070]

The variable capacitance elements 211a and 211b are mutually connected on the drain-source side, and the DC-cut capacitors 213a and 213b of interrupting the direct currents are series-connected to both ends of the series-circuit of the variable capacitance elements 211a and 211b (hereafter, the series circuit formed by the variable capacitance elements 211a and 211b and the DC-cut capacitors 213a and 213b is referred to as a third variable capacitance circuit).

[0071]

The second variable capacitance circuit and the third variable capacitance circuit are connected in parallel, and are connected to the connection terminals 200a and 200b. And the gate side of the second variable capacitance circuit and the gate side of the third variable capacitance circuit are connected to the reference voltage generation means 114 via the resistors 214a and 214b and the resistors 215a and 215b respectively.

[0072]

The drain-source connection side of the second variable capacitance circuit is connected to the frequency control terminal 202, and the drain-source connection side of the third variable capacitance circuit is connected to the output side of the switch 216. One terminal on the input side of the switch 216 is connected

to the frequency control terminal 202, and the other terminal thereon is connected to the power supply.

[0073]

The switch 216 is connected with the control terminal 203, and the control terminal 203 is connected with the frequency band setting terminal 140. And the switch 216 has the configuration wherein one side of the input side of the switch 216 and the other side thereof are switched according to a signal outputted from the frequency band setting terminal 140.

[0074]

Hereafter, the operation of the present invention will be described by referring to Figs. 8 and 9.

[0075]

The voltage-controlled oscillator according to the present invention applies a ground voltage or the power supply voltage to the frequency band setting terminal 141 on starting the operation and thereby changes the capacitance of the variable capacitance elements 141a and 141b of the first variable capacitance circuit so as to select the frequency band to be used. Thereafter, it fine-tunes the oscillation frequency with the control voltage applied to the frequency control terminal 102. The method of switching the frequency band is already described in Japanese Patent Laid-Open No. 2001-196853.

However, as shown in Fig. 10 (a), the method in the past has a problem that the higher the frequency band to be used is, the more abrupt the change in the frequency against the control voltage becomes. The reason for this is that, if the frequency band becomes higher, the capacitance values of the frequency band setting variable capacitance elements 141a and 141b become smaller so that, as a result, the capacitance values of the variable capacitance circuits 144a to 144c become relatively larger against all the parallel capacitance values constituting a resonant circuit.

[0076]

According to the present invention, the variable capacitance circuits indicated by 144a to 144b in Fig. 8 are constituted as shown in Fig. 9, and the capacitance values of the variable capacitance circuits 144a to 144b are changed according to the frequency band so as to change the variable range of the capacitance. To be more specific, in Fig. 9, the variable capacitance elements 210a and 210b are directly connected to the frequency control terminal 202, and the variable capacitance elements 211a and 211b are selectively connected to the frequency control terminal 202 or the power supply voltage by the switch 216. The voltage applied to the control terminal 203 of the switch 216 is switched synchronizing with the

frequency band setting terminal 140. To be more specific, in the case where the frequency band on the low frequency side is used, the input side of the switch 216 is connected to the frequency control terminal 202, and is connected to the power supply voltage side in the case where the frequency band on the high frequency side is used. Therefore, it is possible, by appropriately setting the capacitance values of the variable capacitance elements 210a, 210b, 211a and 211b, to fix the change in the frequency against the control voltage even in the case of switching to a plurality of bands as shown in Fig. 10 (b).

[0077]

Fig. 11 shows another configuration example of the variable capacitors indicated by 144a to 144b in Fig. 8, and the same portions as the circuit shown in Fig. 9 are given the same symbols and a description thereof will be omitted.

[0078]

In Fig. 11, reference numeral 220a and 220b denote the DC-cut capacitors, and 221a and 221b denote the switches. The switch 221a and the capacitor 220a are series-connected, and they are connected so that the capacitor 220a is connected to a capacitor 212a in parallel when the switch 221a is in a connection state. Likewise,

the switch 221b and the capacitor 220b are series-connected, and they are connected so that the capacitor 220b is connected to a capacitor 212b in parallel when the switch 221b is in a connected state. And the switches 220a and 220b are connected to the control terminal 203, and are opened and closed according to the signal outputted from the frequency band setting terminal 140.

[0079]

Hereafter, the operation in the case of using the circuit shown in Fig. 11 as the variable capacitance circuit shown in Fig. 8 will be described by referring to Figs. 8 and 11.

[0080]

The control terminal 203 of the switches 221a and 221b is connected to the frequency band setting terminal 140. In the case where the frequency band on the low frequency side is used, the switches 221a and 221b are set in the connected state. And in the case where the frequency band on the high frequency side is used, the switches 221a and 221b are set in an interrupted state.

[0081]

Now, it is assumed that the capacitance value of the variable capacitance elements 210a and 210b is C_0 , the capacitance value of the DC-cut capacitors 212a and 212b

is C1, and the capacitance value of the DC-cut capacitors 220a and 220b is C2. In this case, a total capacitance value C of 210a, 212a and 220a or 210b, 212b and 220b is represented as follows when the switches 221a and 221b are in the connected state.

[0082]

[Formula 6]

$$C = C_0 \cdot (C_1 + C_2) / (C_0 + C_1 + C_2)$$

And it is represented as follows when the switches 221a and 221b are in the interrupted state.

[0083]

[Formula 7]

$$C = C_0 \cdot C_1 / (C_0 + C_1)$$

And it is possible to change the capacitance value of the entire variable capacitance circuit shown in Fig. 11 according to the operation of the switches 221a and 221b. To be more specific, it is possible, by appropriately lowering the variable range of the capacitance of the variable capacitance elements 210a, 210b, 211a and 211b according to reduction in the capacitance of the first variable capacitance circuit, to fix the change in the frequency against the control voltage even in the case of switching to the plurality of bands as shown in Fig. 10 (b). To be more specific, minute influence of the noise over the control voltage

can be curbed even in the case of using the high frequency band.

[0084]

According to this embodiment, the case of two frequency bands has been described. It is possible, however, to support three or more frequency bands with the same configuration. In that case, of the plurality of voltages, the voltage corresponding to the frequency band is inputted to the first variable capacitance circuit and the variable capacitance circuits 144a to 144c. Here, in the case where the circuit shown in Fig. 9 is used as the variable capacitance circuits 144a to 144c, there is a thinkable configuration wherein a different variable capacitance circuit of the same configuration is further connected in parallel in addition to the second variable capacitance circuit and third variable capacitance circuit, and the power supply voltage is inputted according to the voltage inputted from the frequency band setting terminal 140 as with the second variable capacitance circuit.

[0085]

In the case where the circuit shown in Fig. 11 is used as the variable capacitance circuits 144a to 144c, there is a thinkable configuration wherein the series circuit of the switch and capacitor is further connected

in parallel to the capacitors 212a and 212b, and the capacitor is further connected according to the voltage inputted from the frequency band setting terminal 140.

[0086]

The voltage-controlled oscillator according to this embodiment may also have the configuration wherein the n pieces of variable capacitance circuit exist, at least one of the n pieces of variable capacitance circuit has at least one variable capacitance element, and of the plurality of voltages, the voltage according to the frequency to be used is inputted instead of the control voltage to the terminal on the drain-source side of this at least one variable capacitance element so that the variable range of the capacitance of at least one of the n pieces of variable capacitance circuit is lowered according to the reduction in the capacitance of the variable capacitance element of the first variable capacitance circuit.

[0087]

The voltage-controlled oscillator according to this embodiment may also have the configuration wherein the DC-cut capacitor is comprised of two or more capacitors connected via the switch, and the capacitance of the DC-cut capacitor is reduced as the above switch is on or off according to the frequency to be used so that the variable

range of the capacitance of at least one of the n pieces of variable capacitance circuit is lowered.

[0088]

This embodiment has been described by taking the variable capacitance circuit shown in Fig. 9 or 11 as an example so far. However, the n pieces of variable capacitance circuit is not limited to the example shown in Fig. 9 or 11 but may be the variable capacitance of another configuration. To be more specific, the n pieces of variable capacitance circuit should have the configuration wherein the power supply voltage or the predetermined reference voltage is inputted to some terminals of the variable capacitance elements of the n pieces of variable capacitance circuit, the control voltage of feedback-controlling the oscillation frequency is inputted to the other terminals of the variable capacitance elements of said n pieces of variable capacitance circuits, and when the capacitance of the variable capacitance element of the first variable capacitance circuit becomes lower than the predetermined value, the variable range of the capacitance of at least one of the n pieces of variable capacitance circuit is lowered. In that case, the same effect as described above can be obtained.

[0089]

According to the above description of this embodiment, the capacitors 122a, 122b and 122c are connected to the output side of the reference voltage generation means 114. However, the voltage-controlled oscillator according to this embodiment does not necessarily require the capacitors 122a, 122b and 122c. In that case, the same effect as described above can be obtained.

[0090]

According to the above description of the first and second embodiments, the reference voltages outputted from the reference voltage generation means 114 are inputted to the gate side of each variable capacitance element of the variable capacitance circuits and the control voltages are inputted to the drain-source side of each variable capacitance element of the variable capacitance circuits. However, it may also be the configuration wherein the control voltages are inputted to the gate side of each variable capacitance element of the variable capacitance circuits and the reference voltages are inputted to the drain-source side of each variable capacitance element of the variable capacitance circuits.

[0091]

According to the above description, the variable capacitance elements are those utilizing the gate capacitance used in the CMOS process. However, the

variable capacitance elements may be another type of variable capacitance elements. In that case, the reference voltages should be inputted to one side of each variable capacitance element and the control voltages should be inputted to the other side thereof, and the same effect as described above can be obtained.

[0092]

According to the above description, MOS transistors are used as the oscillation transistors. However, bipolar transistors may also be used.

[0093]

The scope of the present invention also includes a radio communication apparatus having the voltage-controlled oscillator according to the first and second embodiments and also having a PLL circuit of outputting the signal of a target frequency.

[0094]

As described above, it is possible, according to the present invention, to moderate the change in the oscillation frequency against the control voltage of the voltage-controlled oscillator even in the case of using the variable capacitance elements of low linearity. Therefore, it is possible to maintain constant transient response characteristic and noise band characteristic of the PLL circuit over a wide band and connect a

large-capacitance bypass capacitor in parallel to the output signal from the reference voltage generation means so as to realize the oscillator of a good phase noise characteristic.

[0095]

According to the present invention, it is possible to provide a voltage-controlled oscillator capable of curbing degradation of a phase noise characteristic and keeping compliance of a control voltage unreduced, and a radio communication apparatus and a voltage-controlled oscillation method using the voltage-controlled oscillator. Alternatively, it is possible to provide a voltage-controlled oscillator, a radio communication apparatus and a voltage-controlled oscillation method which enable to curb degradation of a phase noise characteristic.

[Brief Description of the Drawings]

[Fig. 1]

Fig. 1 is a circuit diagram showing a configuration of a voltage-controlled oscillator according to a first embodiment of the present invention;

[Fig. 2]

Fig. 2 is a diagram for explaining a principle the first embodiment of the present invention;

[Fig. 3]

Fig. 3 is a circuit diagram showing the configuration of reference voltage generation means according to the first embodiment of the present invention;

[Fig. 4]

Fig. 4 is a circuit diagram showing the configuration of reference voltage generation means according to the first embodiment of the present invention;

[Fig. 5]

Fig. 5 is a circuit diagram showing the configuration of reference voltage generation means according to the first embodiment of the present invention;

[Fig. 6]

Fig. 6 is a circuit diagram showing the configuration of reference voltage generation means according to the first embodiment of the present invention;

[Fig. 7]

Fig. 7 is a circuit diagram showing the configuration of reference voltage generation means according to the first embodiment of the present invention;

[Fig. 8]

Fig. 8 is a circuit diagram showing the configuration of the voltage-controlled oscillator according to a second embodiment of the present invention;

[Fig. 9]

Fig. 9 is a circuit diagram showing the configuration of a variable capacitance according to the second embodiment of the present invention;

[Fig. 10]

Fig. 10 is a diagram for explaining a principle the second embodiment of the present invention;

[Fig. 11]

Fig. 11 is a circuit diagram showing another configuration example of the variable capacitance according to the second embodiment of the present invention;

[Fig. 12]

Fig. 12 is a circuit diagram showing the configuration of the voltage-controlled oscillator in the past;

[Fig. 13]

Fig. 13 is a diagram showing change in a capacitance value against a control voltage of a MOS capacitance;

[Fig. 14]

Fig. 14 is a circuit diagram showing the configuration in a conventional example;

[Fig. 15]

Fig. 15 is a diagram for explaining the principle of the conventional example;

[Description of Symbols]

100 Power source terminal 101 current source

102 Frequency control terminal 103a, 103b Oscillation
transistors

104a, 104b Inductors

105a, 105b, 106a, 106b, 107a, 107b Variable capacitance
elements

108a, 108b, 109a, 109b, 110a, 110b DC-cut capacitors

111a, 111b, 112a, 112b, 113a, 113b High-frequency
blocking resistors

114 Reference voltage generation means

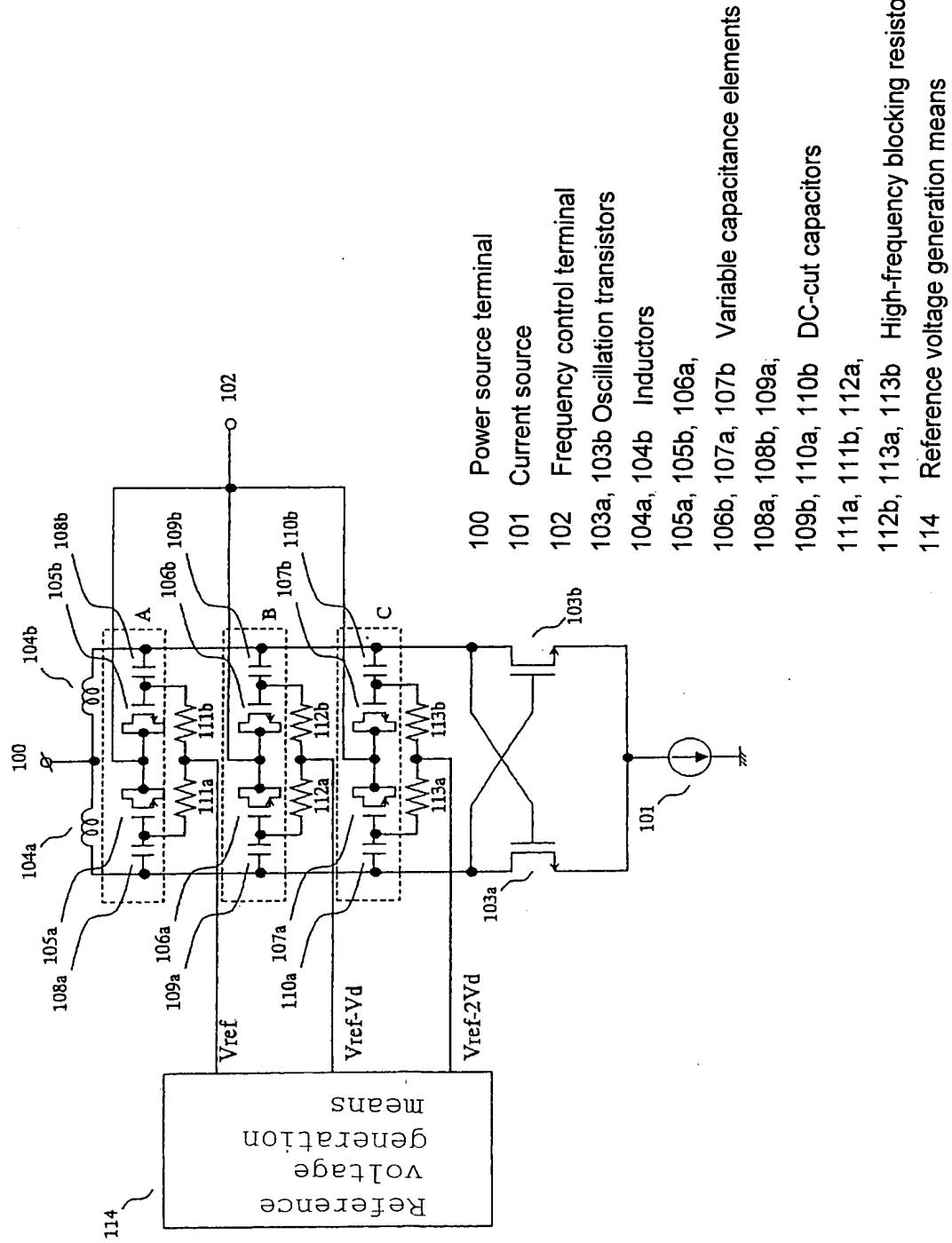
Fig. 1

Fig. 2 (a)

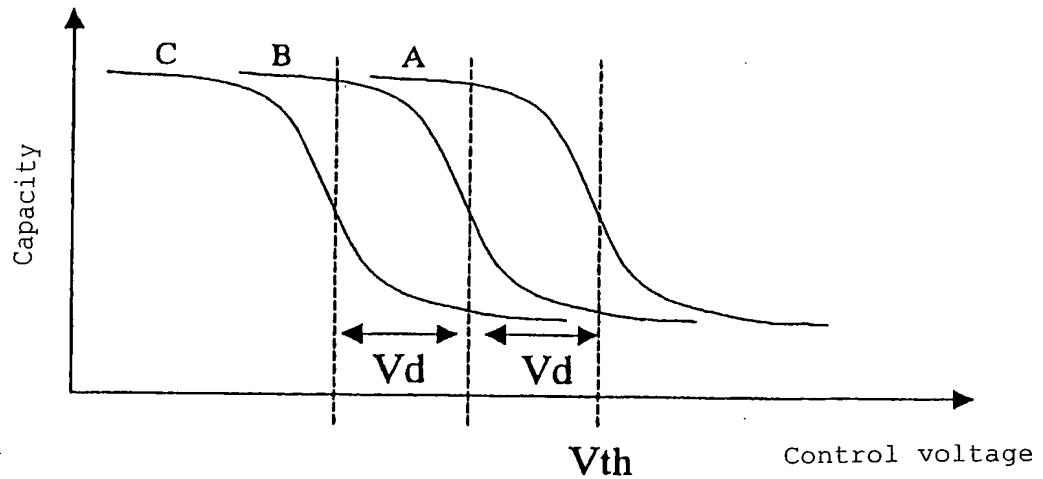


Fig. 2 (b)

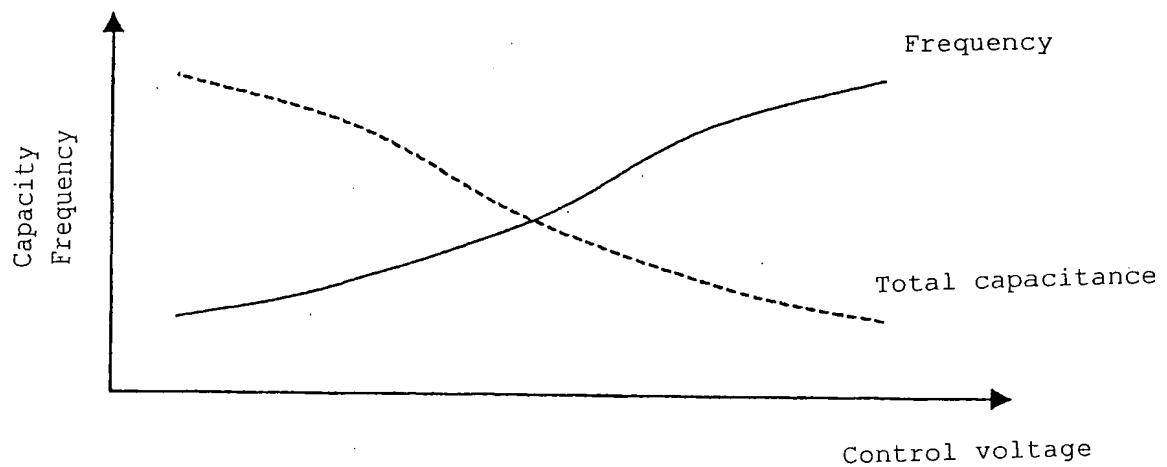


Fig. 3

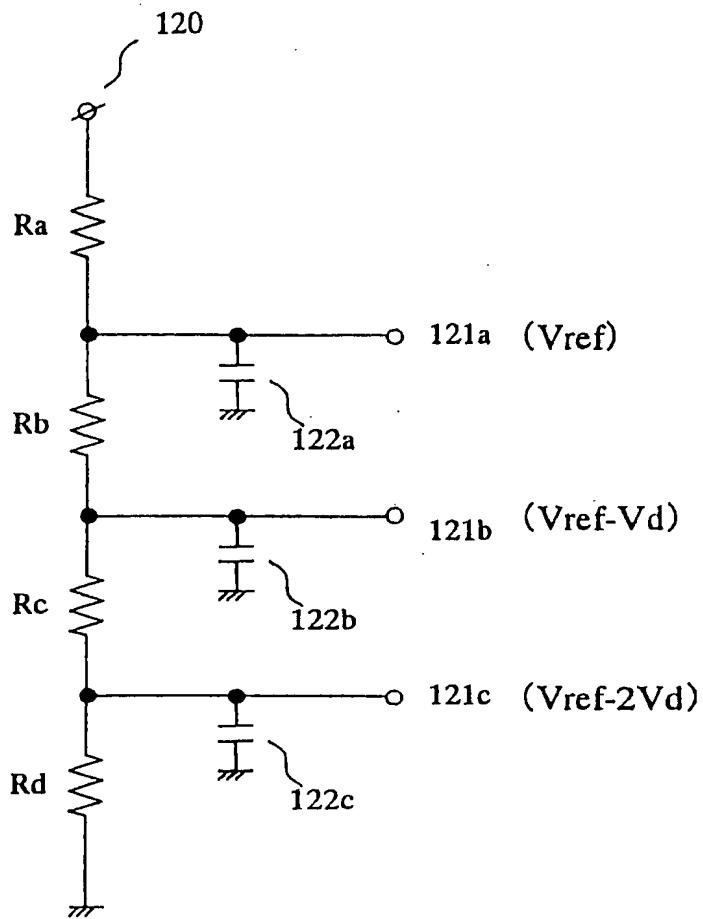


Fig. 4

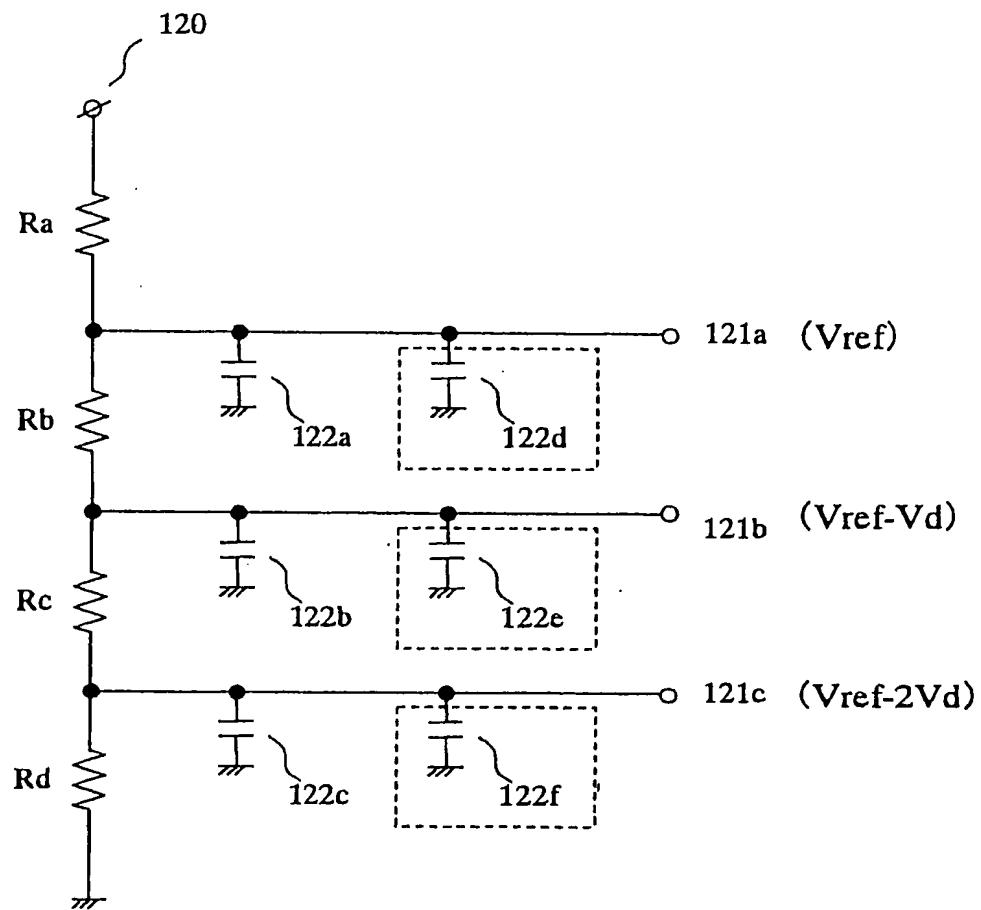


Fig. 5

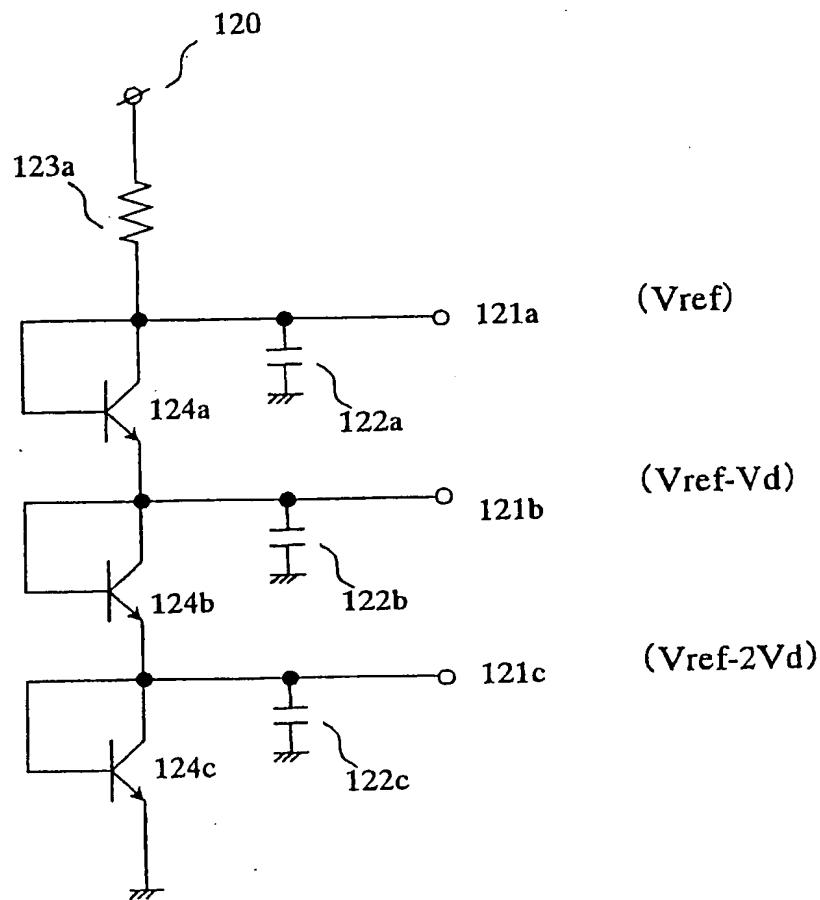


Fig. 6

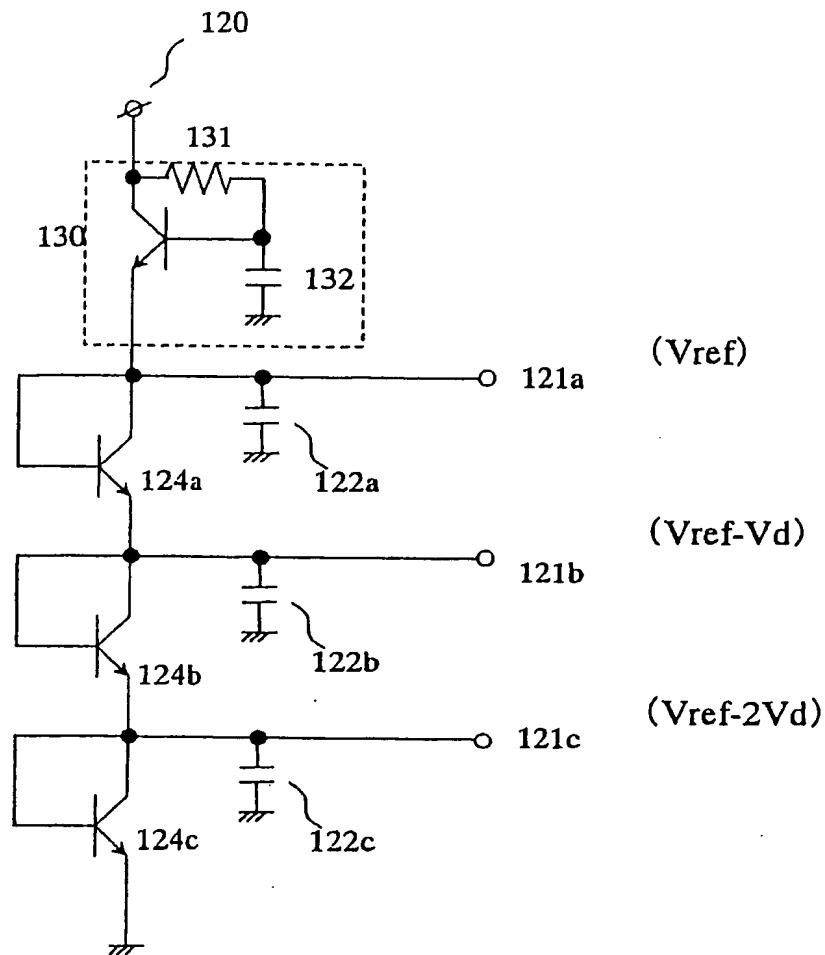


Fig. 7

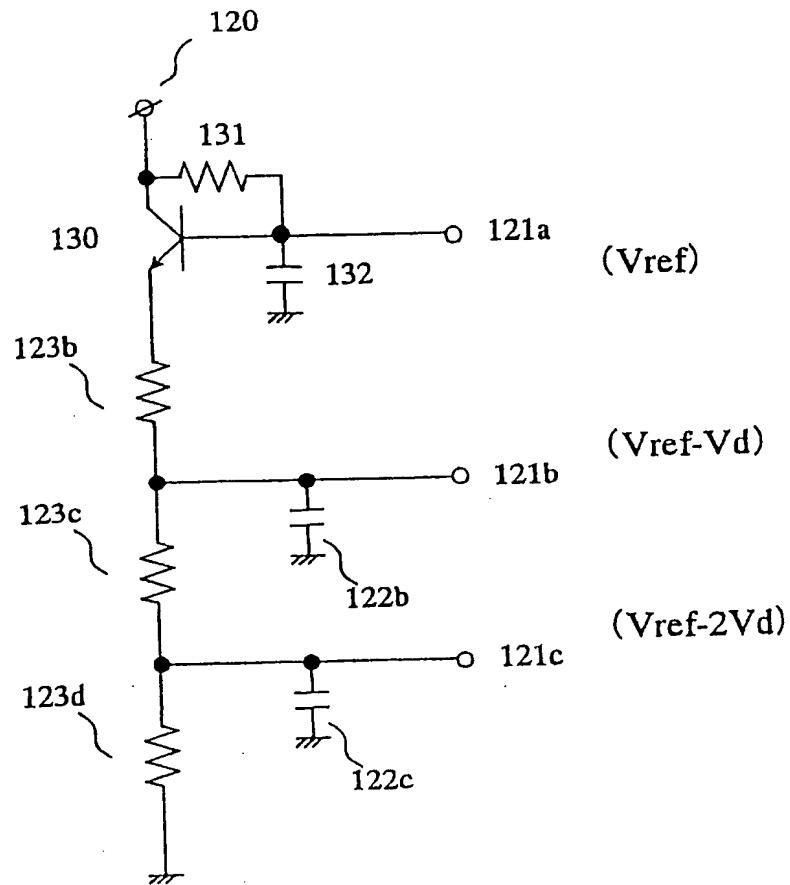


Fig. 8

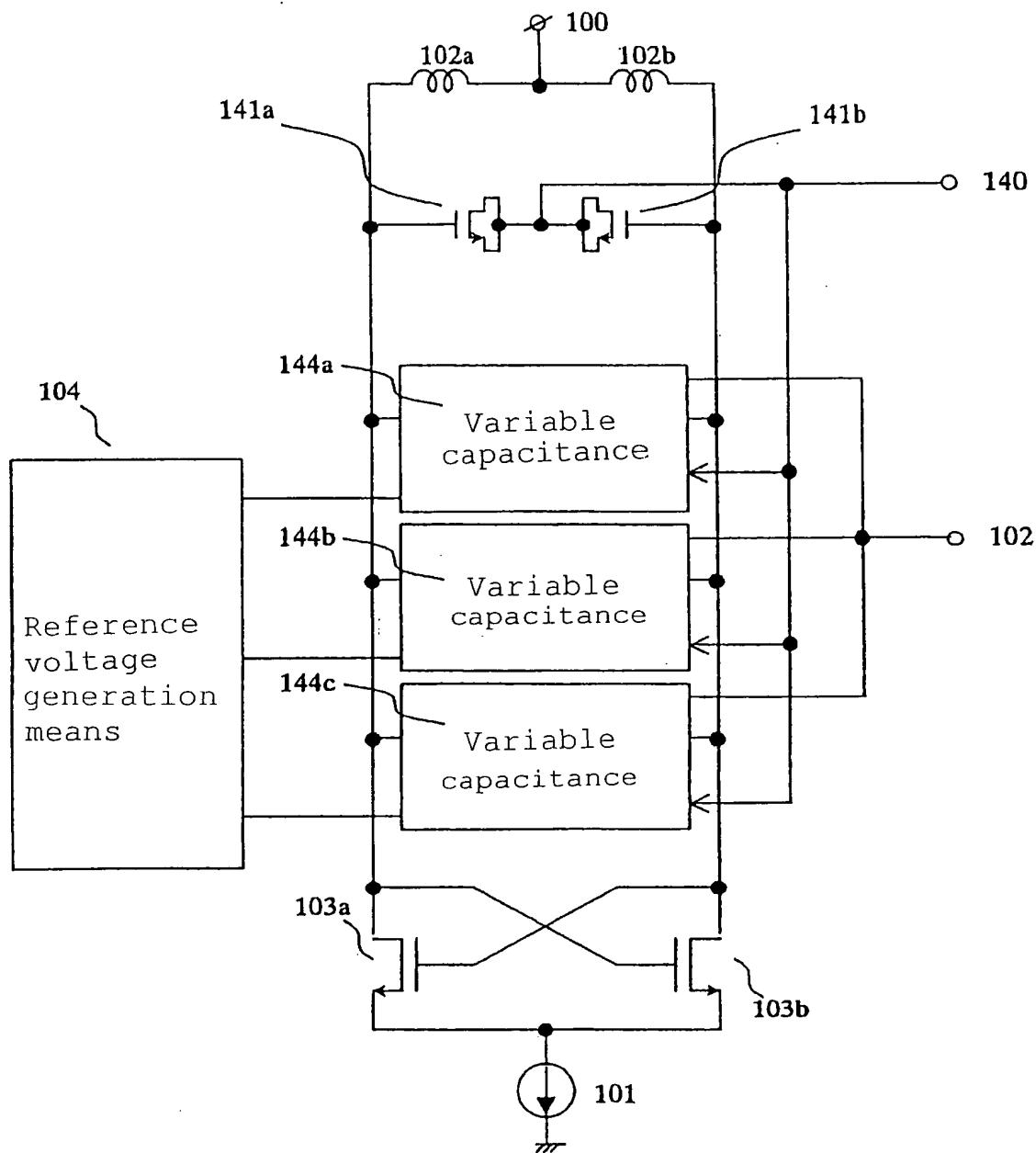


Fig. 9

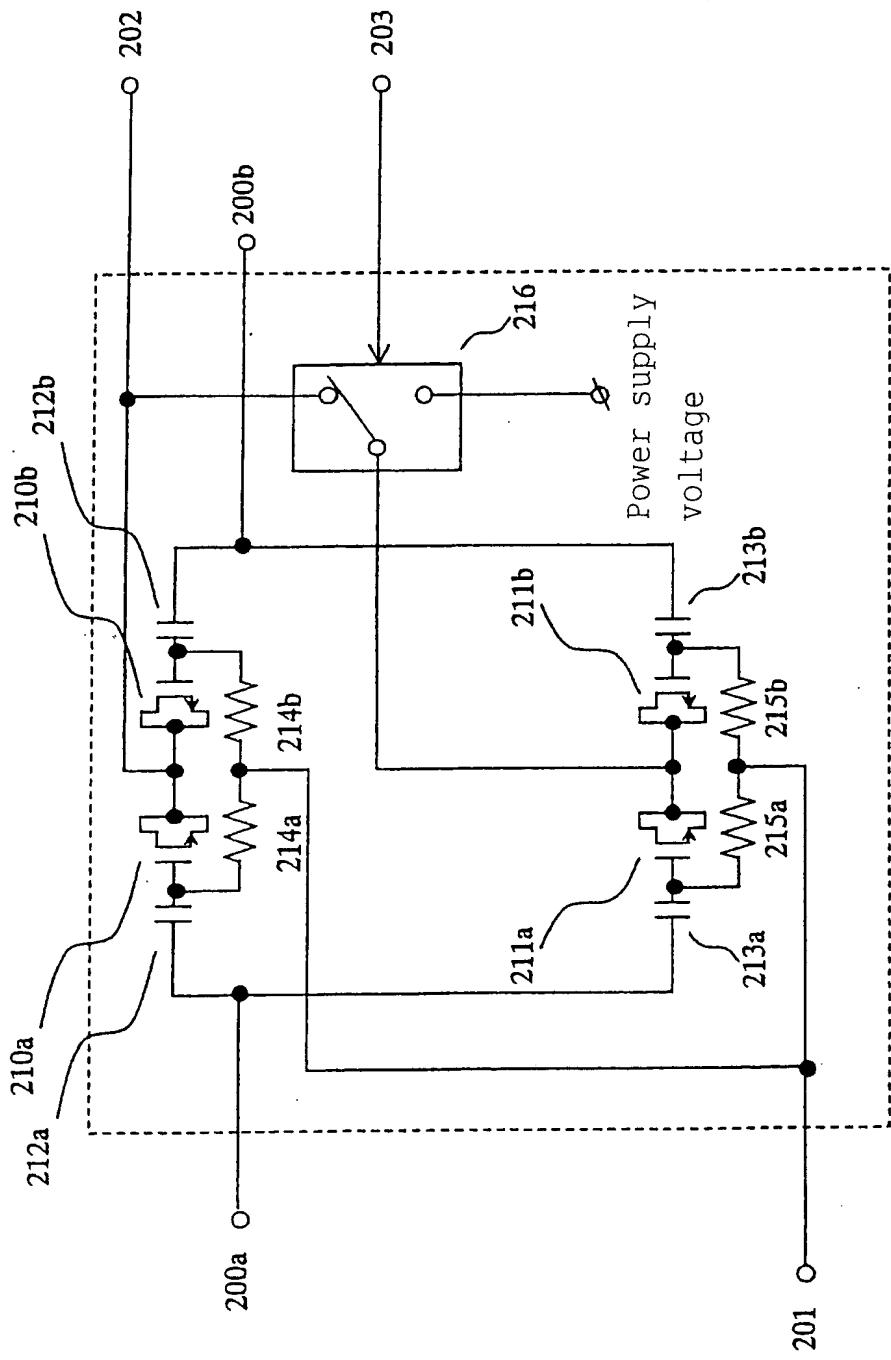


Fig. 10 (a)

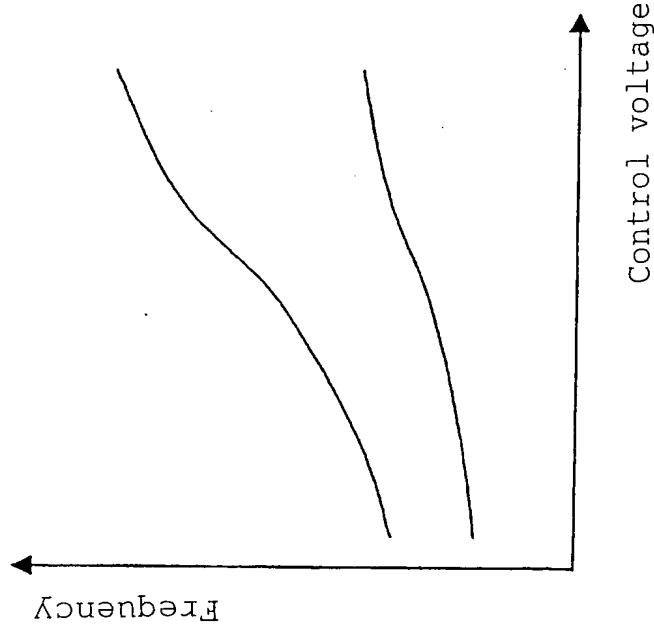


Fig. 10 (b)

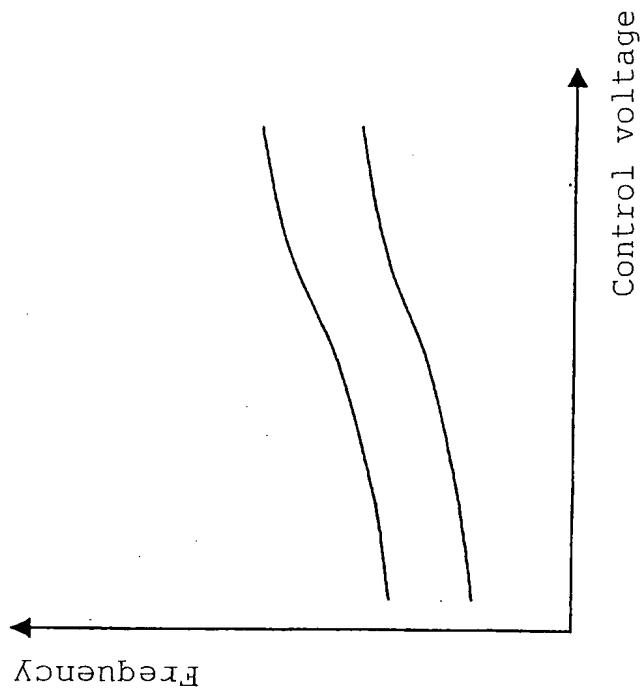


Fig. 11

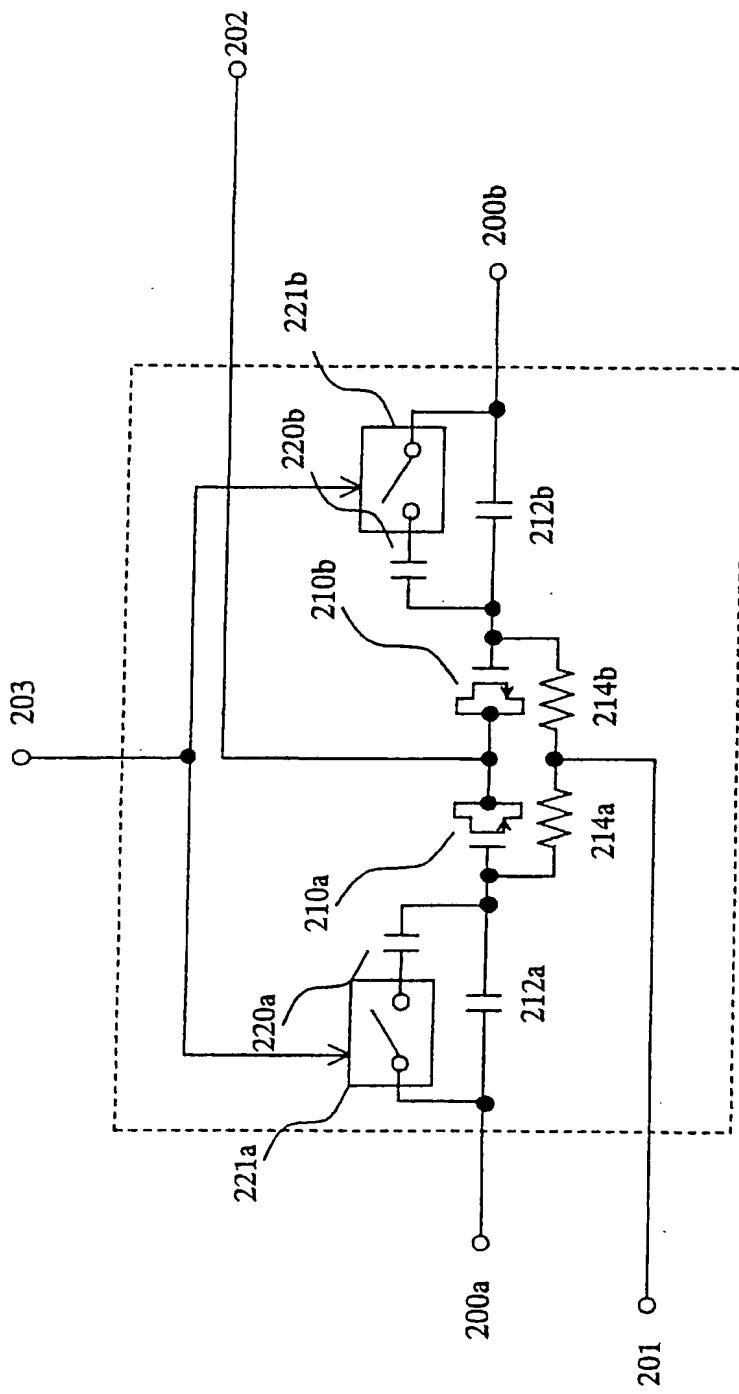


Fig.12

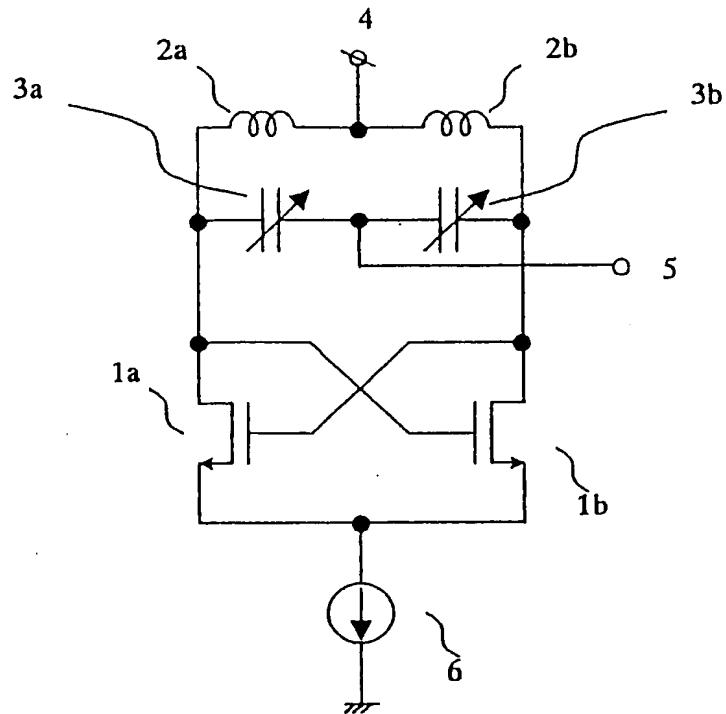


Fig.13 (a)

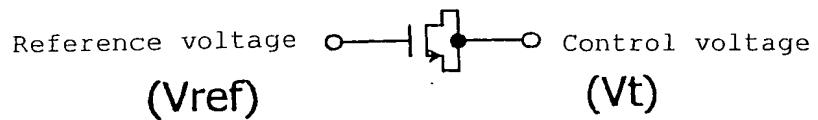


Fig.13 (b)

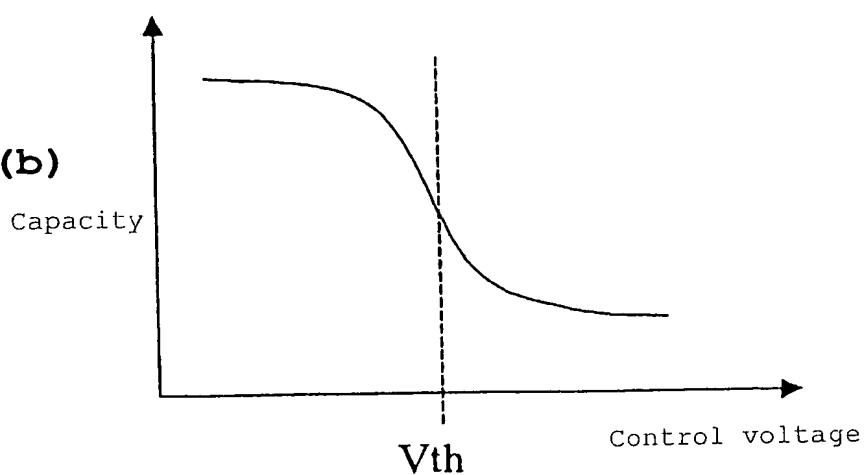


Fig.14

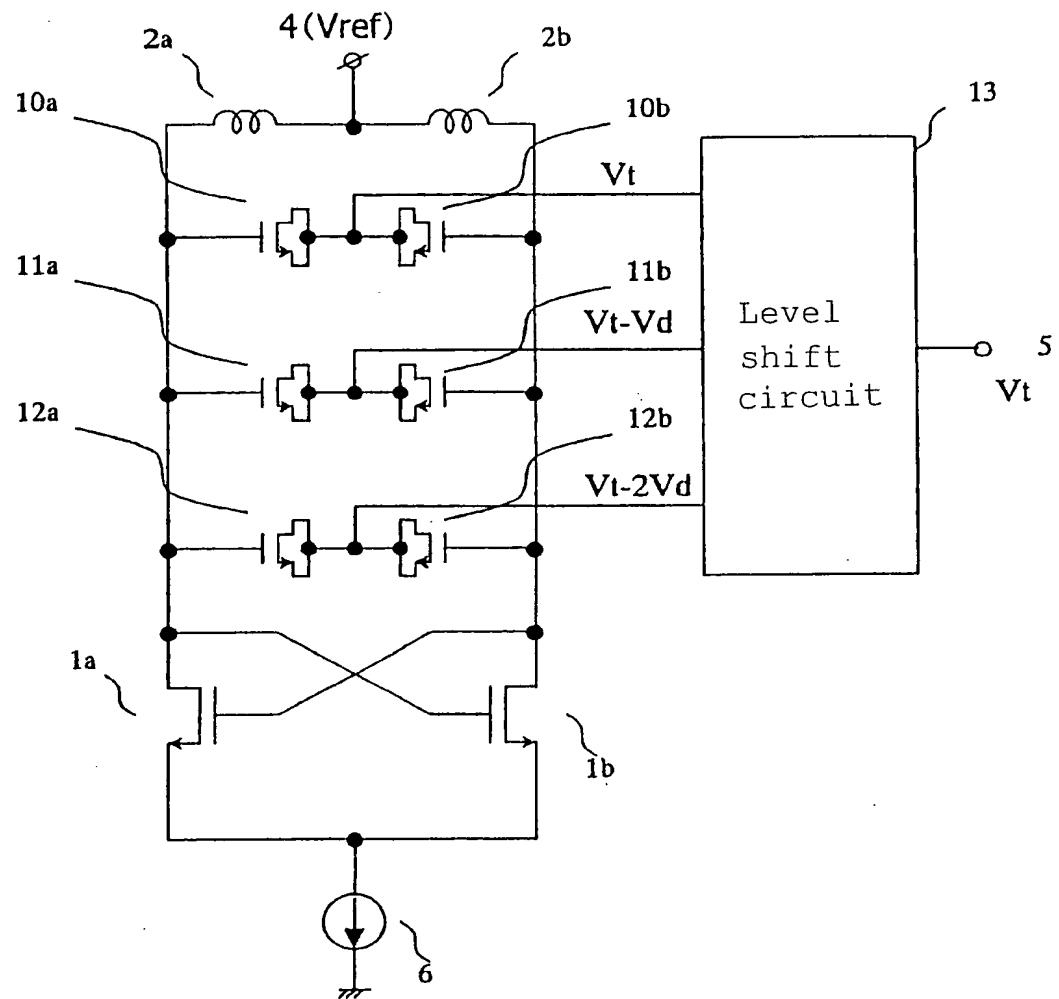
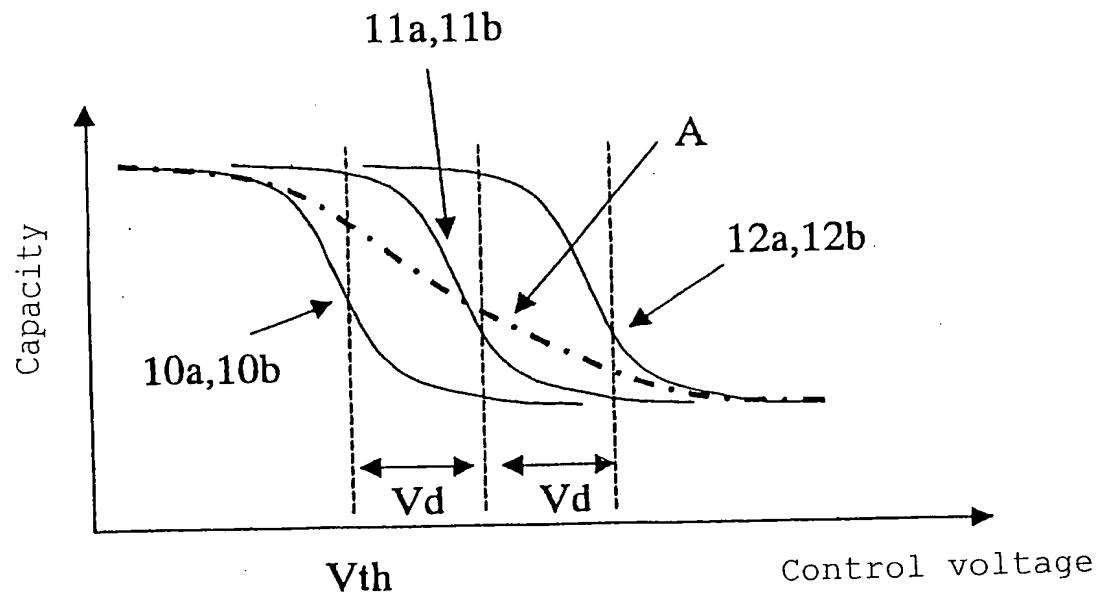


Fig.15



[Document Name] Abstract of Disclosure

[Abstract]

[Object]

To provide a voltage-controlled oscillator capable of curbing degradation of a phase noise characteristic and keeping compliance of a control voltage unreduced, and a radio communication apparatus and a voltage-controlled oscillation method using the voltage-controlled oscillator.

[Solution]

The voltage-controlled oscillator having an inductor circuit, n pieces (n is two or more) of variable capacitance circuit having variable capacitance elements 105a, 105b, negative resistance circuits 103a, 103b, and reference voltage generation means 114 of generating a reference voltage from a power supply voltage, and wherein a predetermined reference voltage is inputted to some terminals of the variable capacitance elements of the n pieces of variable capacitance circuit, a control voltage is inputted to the other terminals thereof, and of the variable capacitance elements of the n pieces of variable capacitance circuits, the predetermined reference voltage inputted to some terminals of the variable capacitance elements of at least two pieces of the variable capacitance circuit is different; and

wherein output sides of outputting said reference voltages of said reference voltage generation means 114 are grounded via capacitors respectively.

[Selected Drawing] Figure 1